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著者	山本 敬三, 伊藤 佑樹, 新開谷 深
journal or publication title	Bulletin of Hokusho University School of Lifelong Sport
volume	8
page range	1-6
year	2017
URL	http://id.nii.ac.jp/1136/00002564/

陸上競技・競歩の衝撃吸収局面における下肢関節の バイオメカニクスの役割

Biomechanical role of joints of lower limb during shock absorbing phase in race walking.

山 本 敬 三 ¹⁾	伊 藤 佑 樹 ²⁾
Keizo YAMAMOTO	Yuki ITO
新 開 谷 深 ²⁾	
Fukashi SHINKAIYA	

Abstract

The purpose of this study was to investigate the role of each joint of the lower limb during the shock absorbing phase in race walking (RW) by comparing it with normal walking (Walk) and running (Run). Three active race walkers participated in this study. They performed RW, walk and Run (forefoot-strike) with self-selected speed in a motion capture laboratory. An optical 3D motion capturing system with two force plates were used. The vertical range of displacement of the center of mass in RW was the smallest among the three movements. The negative power at the ankle and knee joint were hardly detected in RW, however, a relatively large negative power was observed at the hip joint. The negative works of both total and individual joint were obtained by integrating the negative power during the shock absorbing phase. The total negative work in Walk (0.14 W/kg) was the smallest among the three motions. The ratio of the hip joint in RW was greater (36.7%) than the other joints.

本研究の目的は、陸上競技の競歩（race walk, 以下RW）の衝撃吸収局面における下肢の各関節の役割を、正常歩行（Walk）および走行（Run）と比較して調べることにした。本研究には3人の現役の競歩選手が参加した。動作計測では、光学式三次元動作分析装置と床反力計2台を用いて、RW, Walk, Run（前足部接地）を自己選択のスピードで実行した。分析では、重心、床反力、関節角度、関節モーメントおよび関節パワーに着目した。関節については、下肢三関節（股・膝・足関節）を分析対象とした。RWにおける重心の鉛直方向の変動幅は、3つの動作の中で最小であった。RWでは足関節および膝関節の負のパワーはほとんど検

1) School of Lifelong Sport, Hokusho University, Ebetsu, Japan

2) Graduate School of Hokusho University, Ebetsu, Japan

KEY WORDS : shock absorption, joint moment, joint power, negative work

出されなかったが、股関節では比較的大きな負のパワーが発揮された。衝撃吸収局面における負のパワーを時間積分することによって、各関節と下肢三関節の合成の負の仕事量を算出した。Walkにおける負の全仕事量は、3つの運動の中で最も小さかった (0.14W/kg)。RWにおける股関節の負の仕事量の割合は膝・足関節のそれよりも大きかった (36.7%)。

INTRODUCTION: According to the competition rules, the definition of race walking (RW) is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs. The advancing leg shall be straightened (i.e. not bent at the knee) from the moment of initial contact with the ground until the vertical upright position (IAAF competition rule Section VII Rule 230). Hanley et al. (2011, 2013) reported the kinematic characteristics of elite walkers, which showed that the walking speed was associated with both step length and cadence. Men were faster than women because of their greater step lengths but there was no difference in cadence. In the kinetics analysis, there were some reports which measured ground reaction force using force plates and analyzed joint moments and powers in RW (Payne, 1978; White and Winter, 1985; Cairns et al., 1986; Hanley et al., 2014). However, the report that explained the biomechanical mechanism of the shock absorption in detail in RW was not found. The purpose of this study was to investigate the role of each joint of lower limb during the shock absorbing phase in RW by comparing it with normal walking (Walk) and running (Run).

METHODS: Three active race walkers participated in this study (1.71 ± 0.6 m in height, 62.0 ± 4.9 kg in weight, 20.3 ± 1.5 yrs, Mean \pm S.D.). The best records in a 20 km competition for each subject were 1:25'48" , 1:31'52" and 1:37'32" , respectively. They performed Walk, RW and Run (toe-strike) with self-selected speed at the motion analysis laboratory. The walking/running speed were 1.95 ± 0.16 m/s for Walk, 2.98 ± 0.31 m/s for RW and 3.07 ± 0.11 m/s for Run. A total of 31 reflective markers based on the HelenHayes marker set were attached to the subject. An optical 3D motion capturing system (MAC3D system; Motion Analysis, USA, 12 cameras, Sampling Freq. 200 Hz) with two force plates (BP6001200; AMTI, USA, Sampling Freq. 1 kHz) were used. A full-body six-degree-of-freedom kinematic model with functional hip joints was applied using Visual3D (C-motion; Germantown, USA). Raw marker positions and ground reaction forces were filtered at 6 Hz and 18 Hz using a fourth-order recursive Butterworth low pass filter, respectively. The model was then used to calculate joint kinematics and kinetics. The displacement of the vertical center of mass (vCoM) and the vertical ground reaction force (vGRF) curves for each motion were calculated. The vertical range of vCoM (vCoM-range) and the peak values of vGRF (peak vGRF) were

obtained. Based on the joint power curve of the right lower limb, the negative work was obtained by integrating the negative power during the shock absorbing phase. The time range of shock absorbing phase was defined from the initial contact to the lowest point of CoM.

RESULTS: The displacement of the vCoM and the vGRF curves for each motion were depicted in Fig.1. The vCoM-range were $5.5 \pm 0.9\text{cm}$ for Walk, $2.6 \pm 0.9\text{cm}$ for RW and $10.0 \pm 0.8\text{cm}$ for Run (Fig.1(a),(c),(e)). The smallest value was shown in RW. The timing of the lowest CoM appeared at a double-limb support phase in Walk, but it was at a single-limb support phase in both RW and Run. The peak vGRF of Walk, RW and Run were $1.59 \pm 0.17\text{N/kg}$, $1.47 \pm 0.12\text{N/kg}$ and $2.83 \pm 0.11\text{N/kg}$, respectively (Fig.1(b),(d),(f)). The hip, knee and ankle joint power curves of each motion were shown in Fig.2. In both Walk and Run, the negative power was observed at the ankle joint just after an initial contact (Fig.2(c), (i)), soon after the negative power at the knee and hip joint were confirmed (Fig.2(a),(b),(g),(h)). The negative power at both the ankle and knee joint were hardly detected in RW (Fig.2(e),(f)), however, a relatively large positive power was observed just after an initial contact, and relatively large negative power was observed afterwards at the hip joint (Fig.2(d)). The minimum values of the hip joint power were $-1.14 \pm 0.69\text{ W/kg}$ for Walk, $-1.76 \pm 0.68\text{ W/kg}$ for RW and $-1.46 \pm 0.63\text{ W/kg}$ for Run (Fig.2(a),(d),(g)).

The total and ratio of the negative works of the hip, knee and ankle joint during the shock absorbing phase were shown in Fig.3. The smallest total negative work among the three motions was shown in Walk (0.14 W/kg). The ratio that the knee joint accounted for was the greatest at 48.1% in Walk. The ratio of the hip joint was greater (36.7%) than the other joints in RW. In Run, the ratio of the ankle was the biggest (66.7%), and that of the hip joint remained only 3.9%.

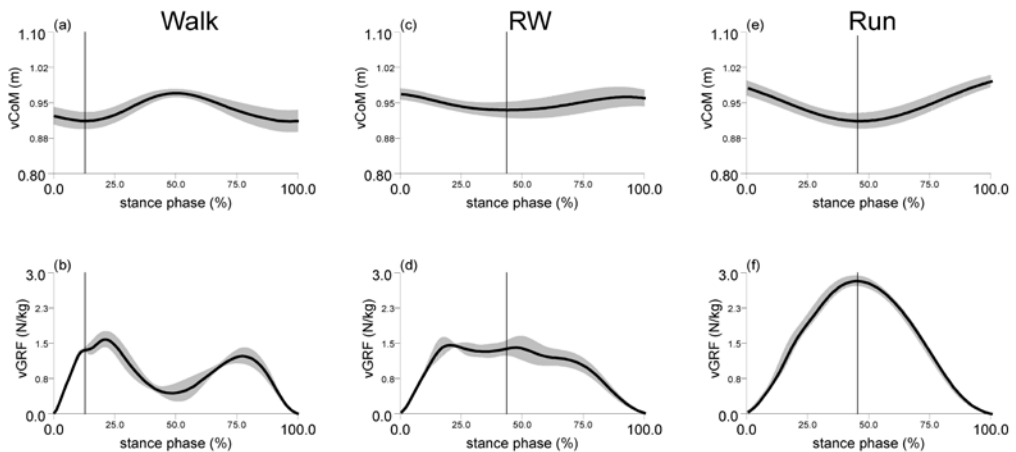


Figure 1: The vertical CoM (Center of Mass) displacements (a,c,e) and vertical GRF (ground reaction force) curve (b,d,f) in the support phase of right leg (mean \pm SD, $n=3$). The vertical line means the timing of the lowest point of vCoM. Walk: normal walking, RW: race walking and Run: running.

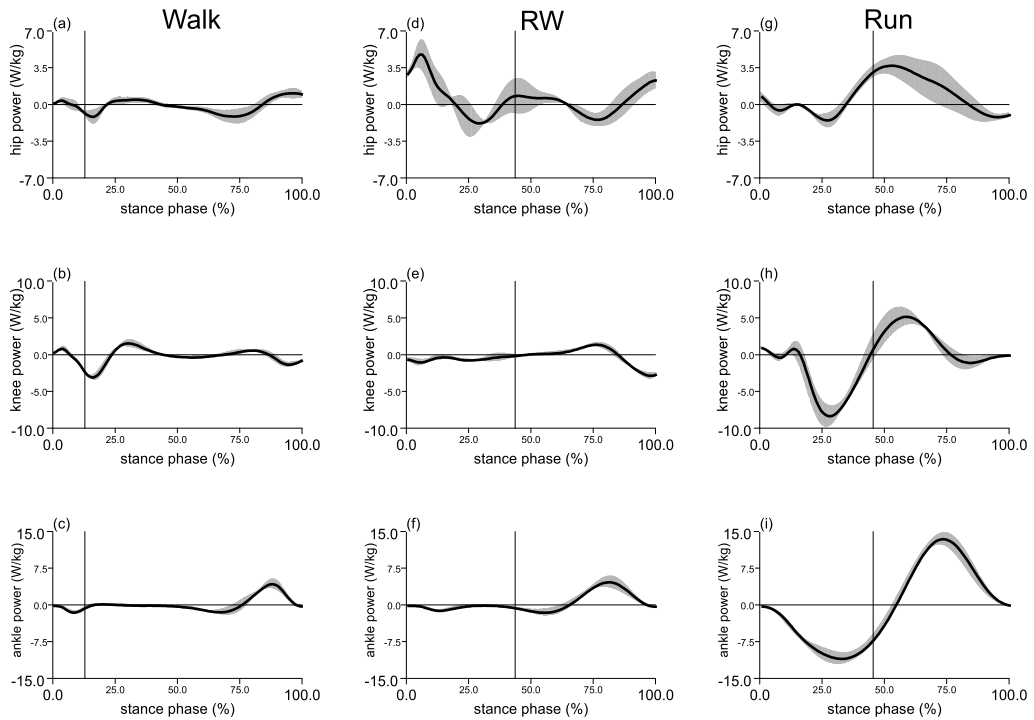


Figure 2: Joint power curve of each joint in the support phase of right leg (mean \pm SD, $n=3$). The vertical line means the timing of the lowest point of vCoM. WALK: normal walking, RW: race walking and Run: running.

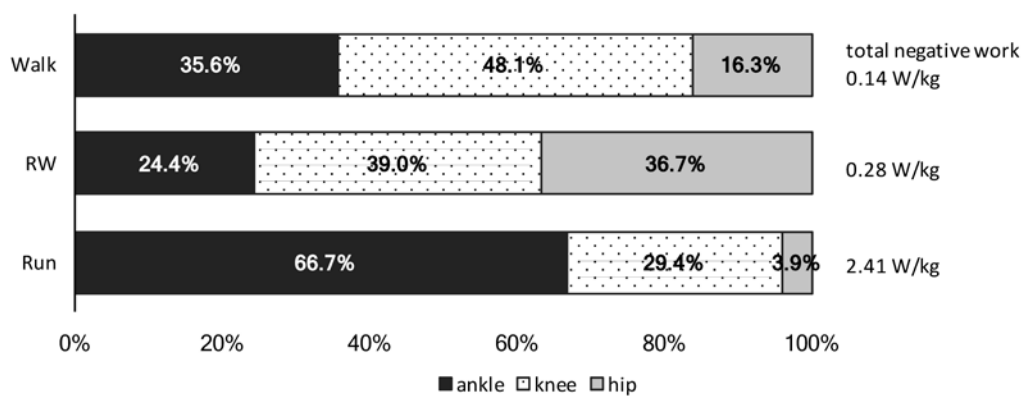


Figure 3: The total and ratio of the negative work for each joint in normal walking (Walk), race walking (RW) and running (Run).

DISCUSSION: Because both the vCoM-range and the peak vGRF in RW were the smallest among the three motions, the landing shock acted upon a race walker would be smaller. That was regarded as the factor that showed that the total negative work of RW was the smallest in the three motions (Fig.3). Murray et al. (1983) mentioned that it was also because it minimized mechanical energy demands during RW. Pavei et al. (2014) reported that the race walker's CoM has a flat trajectory that does not follow a pendulum-like gait as in Walk. On the other hand, in view of the relationship between a motion phase and the displacement of vCoM, the movement mechanism of RW is supposed to be similar to Run rather than Walk. The shock absorption by the knee joint is limited by rule properties of the RW (not bent at the knee, Fig.2(e)), therefore, it is thought that the hip joint is needed to take a main role in the shock absorption (36.7%) instead of the ankle joint (24.4%) in RW (Fig.3). It was suggested that hamstring muscles having functions of knee flexor and hip extensor activated strongly because flexion moment in the knee joint and extension moment in the hip joint were shown just after the initial contact in RW. Those joint moments probably kept a human trunk straight up and controlled a CoM fall. Then, the shock absorption by the eccentric contraction of the hip abductor muscle was carried out. The limitation of this study was a small sample size.

CONCLUSION:

This study found the following findings:

- 1) The vCoM and vGRF curves in RW were similar to those in Run rather than those in Walk.
- 2) The total negative work in RW was smallest among the three motions.
- 3) The hip joint took a main role in the shock absorption in RW instead of a knee or ankle joint.

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Acknowledgement

This work was supported by JSPS KAKENHI (24500750).